Appendix K

Portland District TDG Report Prepared by the USGS (Includes The Dalles, John Day, and Bonneville Dams)

Prepared in cooperation with the U.S. Army Corps of Engineers

Total Dissolved Gas and Water Temperature in the Lower Columbia River, Oregon and Washington, 2007: Quality-Assurance Data and Comparison to Water-Quality Standards

By Dwight Q. Tanner, Heather M. Bragg, and Matthew W. Johnston

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U.S. Geological Survey

U.S. Department of the Interior
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Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Acknowledgments

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Total Dissolved Gas and Water Temperature in the Lower Columbia River, Oregon and Washington, 2007: Quality-Assurance Data and Comparison to Water-Quality Standards

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Significant Findings

When water is released through the spillways of dams, air is entrained in the water, increasing the downstream concentration of dissolved gases. Excess dissolved-gas concentrations can have adverse effects on freshwater aquatic life. The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, collected dissolved-gas and water-temperature data at eight sites on the lower Columbia River in 2007. Significant findings from the data include:

From early July to mid-September 2007, water temperatures were above 20 °C (degrees Celsius) at each of the eight lower Columbia River sites. According to the Oregon temperature standard, the 7-day average maximum temperature of the lower Columbia River should not exceed 20 °C; Washington regulations state that the 1-day maximum should not exceed 20 °C due to human activities.

Most in-situ field checks of total-dissolved-gas sensors with a secondary standard were within ± (plus or minus) 1% saturation after 3 to 4 weeks of deployment in the river. All of the field checks of barometric pressure were within ±2.5 millimeter of mercury of a secondary standard, and water-temperature field checks were all within ±0.2 °C.

For the eight monitoring sites in water year 2007, an average of 99.5% of the total-dissolved-gas data were received in real time by the USGS satellite downlink and were within 1% saturation of the expected value on the basis of calibration data, replicate quality-control measurements in the river, and comparison to ambient river conditions at adjacent sites. Data received from the sites ranged from 97.9% to 100.0% complete.

Introduction

The U.S. Army Corps of Engineers (USACE) operates several dams in the Columbia River Basin (fig. 1), which encompasses 259,000 square miles of the Pacific Northwest. These dams are multipurpose structures that fill regional needs for flood control, navigation, irrigation, recreation, hydropower production, fish and wildlife habitat, water-quality maintenance, and municipal and industrial water supply. When water is released through the spillways of these dams (instead of being routed through the turbines to generate electricity), ambient air is entrained in the water, increasing the concentration of dissolved gases (known as total dissolved gas [TDG]) downstream from the spillways. TDG conditions above 110% saturation can cause gas-bubble trauma in fish and adversely affect other aquatic organisms (U.S. Environmental Protection Agency, 1986).

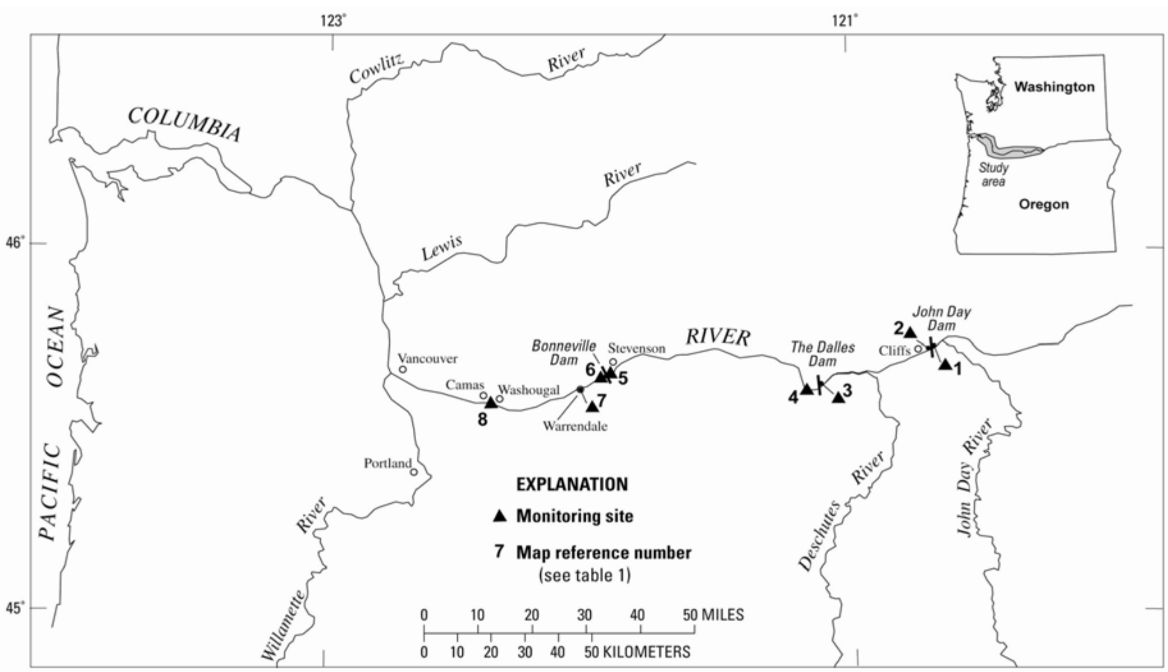

Figure 1. Location of total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2007.

The USACE regulates spill and streamflow to minimize the production of excess TDG downstream from its dams, but there is also a goal of providing for fish passage with spilled water (rather than passage through the turbines). Consequently, the States of Oregon and Washington issue variances to the TDG water-quality standards during the spring and summer. In order to monitor compliance with these variances, the USACE oversees the collection of real-time TDG and water-temperature data upstream and downstream from Columbia River Basin dams in a network of monitoring stations. Data from the lower Columbia River monitoring stations are available within about 1 hour of current time.

Background

Real-time TDG and water-temperature data are vital to the USACE for dam operation and for monitoring compliance with environmental regulations. The data are used by water managers to maintain water-quality conditions that facilitate fish passage and survival in the lower Columbia River. The USGS, in cooperation with the Portland District of the USACE, has collected TDG and related data in the lower Columbia River each year since 1996. Current and historical TDG and water-temperature data can be found on the USGS Oregon Water Science Center Website at *http://oregon.usgs.gov/projs_dir/pn307.tdg/*. Eight reports that were published for water years 1996, 2000, 2001, 2002, 2003, 2004, 2005, and 2006 contain TDG data, quality-assurance data, and descriptions of the methods of data collection (Tanner and others, 1996; Tanner and Johnston, 2001; Tanner and Bragg, 2001; Tanner and others, 2002; Tanner and others, 2003; and Tanner and others, 2004; Tanner and others, 2005; and Tanner and others, 2006).

To insure quality data for managing and modeling TDG in the lower Columbia River, hourly data for 2007 were reviewed relative to laboratory and field measurements made during instrument calibrations and daily intersite comparisons. A small fraction of the TDG data was deleted because they were not of suitable quality. The hourly data were stored in a USGS data base and in a USACE data base (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html*). The USACE data base also includes hourly discharge and spill data.

Purpose and Scope

The purpose of TDG monitoring in the lower Columbia River is to provide the USACE with (1) real-time data for managing streamflow and spill at its project dams, (2) reviewed TDG data to evaluate conditions relative to water-quality standards, and (3) data for modeling the effect of various management scenarios of streamflow and spill on TDG levels.

This report describes the TDG data and related quality-assurance data from the lower Columbia River at eight sites, from the navigation lock of the John Day Dam (river mile [RM] 215.7) to Camas, Washington (RM 121.7), (fig. 1, table 1). Data for water year 2007 (October 1, 2006, to September 30, 2007) include hourly measurements of TDG pressure, barometric pressure, water temperature, and probe depth. Five of the sites (John Day navigation lock, The Dalles forebay, Bonneville, Cascade Island, and Camas) were operated from February or March to September 2007, which is the usual time of spill from the dams. John Day tailwater and The Dalles tailwater were operated year-round and Warrendale was operated year-round except for a period of time from June to mid-September, when site operation was stopped at the request of the USACE.

Table 1. Total-dissolved-gas monitoring stations, lower Columbia River, Oregon and Washington, water year 2007

[Map reference number refers to figure 1; USACE, U.S. Army Corps of Engineers; Columbia River mile locations were determined from U.S. Geological Survey (USGS) 7.5-minute topographic maps; stations in this report are referenced by their abbreviated name or USACE site identifier; °, degree; ’, minute; ”, second]

Map number	USACE site identifier	River mile	USGS station number	USGS station name (and abbreviated station name)	Latitude	Longitude	Period of record
1	JDY	215.7	454314120413701	Columbia River at John Day navigation lock, Washington (John Day navigation lock)	45° 43’ 14”	120° 41’ 37”	03/28/07–09/30/07
2	JHAW	214.7	454249120423500	Columbia River, right bank, near Cliffs, Washington (John Day tailwater)	45° 42’ 49”	120° 42’ 35”	Year-round
3	TDA	192.6	453712121071200	Columbia River at The Dalles Dam forebay, Washington (The Dalles forebay)	45° 37’ 12”	121° 07’ 12”	03/28/07–09/30/07
4	TDDO	188.9	14105700	Columbia River at The Dalles, Oregon (The Dalles tailwater)	45° 36’ 27”	121° 10’ 20”	Year-round
5	BON	146.1	453845121562000	Columbia River at Bonneville Dam forebay, Washington (Bonneville forebay)	45° 38’ 45”	121° 56’ 20”	02/21/07–09/14/07
6	CCIW	145.9	453845121564001	Columbia River at Cascade Island, Washington (Cascade Island)	45° 38’ 45”	121° 56’ 40”	02/22/07–09/30/07
7	WRNO	140.4	453630122021400	Columbia River, left bank, near Dodson, Oregon (Warrendale)	45° 36’ 30”	122° 02’ 14”	10/01/06–05/31/07 and 09/20/07–09/30/07
8	CWMW	121.7	453439122223900	Columbia River, right bank, at Washougal, Washington (Camas)	45° 34’ 39”	122° 22’ 39”	02/21/07–09/20/07

Methods of Data Collection

Methods of data collection for TDG, barometric pressure, and water temperature are described in detail in Tanner and Johnston (2001). A summary of these methods follows: Instrumentation at each monitoring station consists of a Hydrolab water-quality probe, a Vaisala electronic barometer, a power supply, and a Sutron SatLink2 data-collection platform (DCP). The instruments at each site are powered by a 12-volt battery that is charged by a solar panel and/or a 120-volt alternating-current line. At the beginning of the monitoring season in February or March, a new TDG membrane is installed on each Hydrolab. Measurements (including probe depth) are made, logged, and transmitted every hour. The DCP transmits the most recent logged data to the Geostationary Operational Environmental Satellite (GOES) system (Jones and others, 1991). The data are automatically decoded and transferred to the USACE data base and to the USGS data base.

The eight fixed-station monitors were calibrated every 3 weeks, except from October 2006 through March 2007, when they were calibrated at 4-week intervals. The field calibration procedure was as follows: A Hydrolab (which was calibrated several days before the field trip and used as a secondary standard) was deployed alongside of the field Hydrolab for a period of up to 1 hour to obtain check measurements of TDG and water temperature prior to removing the field Hydrolab (which had been deployed for 3 or 4 weeks). The field Hydrolab was then replaced with another Hydrolab that had been calibrated recently at the laboratory and the secondary standard used again to check TDG and temperature measured by the newly deployed Hydrolab in the river. The equilibration process for the newly-placed Hydrolab usually lasted about 1 hour. The electronic barometer at the fixed station was calibrated using a portable barometer (Suunto, Escape 203) that had been recently calibrated at the National Weather Service facility in northeast Portland.

During each field calibration, the minimum compensation depth was calculated to determine whether the Hydrolab was positioned at an appropriate depth to measure TDG. This minimum compensation depth, which was calculated according to Colt (1984, page 104), is the depth above which degassing will occur due to decreased hydrostatic pressure. To measure TDG accurately, the Hydrolabs were positioned during each calibration visit at a depth below the calculated minimum compensation depth whenever possible. During water year 2007, maintaining the probes below the minimum compensation depth was not a problem.

The Hydrolab that was brought from the field after 3 or 4 weeks of deployment was then calibrated in the laboratory. The integrity of the TDG membrane was checked, then the membrane was removed and air-dried. The TDG sensor (without the membrane attached) was calibrated at 0, 100, 200, and 300 mm Hg (millimeters of mercury) above atmospheric pressure to cover the expected range of TDG in the river (approximately 100, 113, 126, and 139% saturation, respectively).

Summary of Total-Dissolved-Gas Data Completeness and Quality

A summary of USGS TDG data completeness and quality for water year 2007 is shown in table 2. (The USACE satellite downlink was a parallel system, so the amount and quality of data received by the USACE were almost identical). Data in table 2 were based on the total amount of hourly TDG data that could have been collected during the monitoring season. Any hour without TDG pressure data or barometric pressure data was counted as an hour of missing data for TDG in percent saturation, which is calculated as TDG pressure, in millimeters of mercury, divided by the barometric pressure, in millimeters of mercury, multiplied by 100. The fourth column in table 2 shows the percentages of data that were received in real time and passed quality-assurance checks. TDG data were considered to meet quality-assurance standards if they were within ± (plus or minus) 1% saturation of the expected value, based on calibration data, replicate quality-control measurements in the river, and daily comparisons to ambient river conditions at adjacent sites. At each station, at least 97.9% of the data were received in real time by the USGS downlink and met quality-control checks, with an overall average of 99.5% (table 2).

Table 2. Total-dissolved-gas data completeness and quality, lower Columbia River, Oregon and Washington, water year 2007

[Results are based on values in USGS ADAPS database; TDG, total dissolved gas]

Abbreviated Station Name	Planned Monitoring in Hours	Number of Missing or Deleted Hourly Values	Percentage of Real-Time TDG Data Passing Quality Assurance
John Day navigation lock	4,476	93	97.9
John Day tailwater	8,760	62	99.3
The Dalles forebay	4,471	27	99.4
The Dalles tailwater	8,760	8	99.9
Bonneville forebay	4,918	3	99.9
Cascade Island	5,290	1	100.0
Warrendale	6,079	11	99.8
Camas	5,066	25	99.5
Average	--	--	99.5

Table 3 is a chronological list of the major portions of data that were either missing from the database (for example, when data telemetry failed) or data that were later deleted from the database because they did not meet quality-assurance standards. Table 3 includes temperature and depth data, whereas table 2 includes only TDG data. The John Day navigation lock site had the most missing or deleted data. Data loss for TDG and temperature data at that site in June was caused by a faulty cable, which was replaced. At the John Day tailwater site, data were missing intermittently in September and could not be recovered or reconstructed. At Camas, there were several episodes in July, August, and September of missing data, probably due to fishing boats docking overnight and blocking the DCP antenna. These data were recovered later and restored to the data bases.

Table 3. Major portions of missing or deleted data, water year 2007

[Site abbreviations: JDY, John Day navigation lock; JHAW, John Day tailwater; TDDO, The Dalles tailwater; BON, Bonneville forebay; CCIW, Cascade Island; WRNO, Warrendale; CWMW, Camas. Parameter and unit abbreviations: TDG, total dissolved gas; BP, barometric pressure; WT, water temperature]

Date & Time	Site	Parameter	Reason / Notes
6/08/07 09:00 through 6/12/07 12:00	JDY	TDG, WT	Faulty cable, data not recovered
11/20/06 13:00 through 11/20/06 16:00	JHAW	TDG	Slow equilibrations, data not recovered
11/28/06 23:00 through 11/29/06 02:00	JHAW	TDG, BP, WT	No data transmission, data were recovered
5/30/07 16:00	JHAW	WT	Erroneous, data not recovered
9/04/07 12:00 through 9/17/07 19:00	JHAW	TDG, WT	Intermittent cable or probe problem, data not recovered
8/01/07 12:00 through 9/04/07 07:00	TDA	TDG, BP, WT	Intermittent episodes of an onsite crane blocking the antenna transmissions, data were recovered
11/28/07 23:00 through 11/29/07 02:00	TDDO	TDG, BP, WT	No data transmission, data were recovered
1/29/07 15:00	TDDO	WT	Calibration, data not recovered
2/17/07 01:00 through 2/17/07 03:00	TDDO	TDG, BP, WT	No data transmission, data were recovered
7/13/07 11:00	BON	TDG, WT	Calibration, data not recovered
8/01/07 12:00 through 8/01/07 13:00	BON	TDG, BP, WT	No data transmission, data were recovered
9/16/07 07:00	CCIW	TDG, BP, WT	No data transmission, data were recovered
11/29/06 00:00 through 11/30/06 07:00	WRNO	TDG, BP, WT	No data transmission, data were recovered

Table 3. Major portions of missing or deleted data, water year 2007—continued

[Site abbreviations: JDY, John Day navigation lock; JHAW, John Day tailwater; TDDO, The Dalles tailwater; BON, Bonneville forebay; CCIW, Cascade Island; WRNO, Warrendale; CWMW, Camas. Parameter and unit abbreviations: TDG, total dissolved gas; BP, barometric pressure; WT, water temperature]

Date & Time	Site	Parameter	Reason / Notes
2/17/07 01:00 through 2/17/07 03:00	WRNO	TDG, BP, WT	No data transmission, data were recovered
7/22/07 22:00 through 7/23/07 03:00	CWMW	TDG, BP, WT	No data transmission, ship possibly blocking antenna, data were recovered
8/01/07 12:00 through 8/01/07 13:00	CWMW	TDG, BP, WT	No data transmission, data were recovered
8/05/07 22:00 through 8/06/07 03:00	CWMW	TDG, BP, WT	No data transmission, ship possibly blocking antenna, data were recovered
9/15/07 22:00 through 9/17/07 02:00	CWMW	TDG, BP, WT	No data transmission, ship possibly blocking antenna, data were recovered

Quality-Assurance Data

Data collection for TDG, barometric pressure and water temperature involve several quality-assurance procedures, including calibration of instruments in the field and in the laboratory, daily checks of the data, and data review and archive. These methods are explained in detail in Tanner and Johnston (2001), and the results of the quality-assurance data for water year 2007 are presented in this section.

After field deployment for 3 or 4 weeks, the TDG sensors were calibrated in the laboratory. First, the instrument was tested, with the membrane in place, for response to increased pressure and to super-saturation conditions. The membrane was then removed from the sensor and allowed to dry for approximately 24 hours. Before replacing the membrane, the TDG sensor was examined independently. The calibration test procedure compared the reading of the TDG sensor to barometric pressure (100% saturation). Using a certified digital pressure gage (primary standard), comparisons were also made at added pressures of 100, 200 and 300 mm Hg above barometric pressure (approximately 113%, 126% and 139% saturation, respectively). The accuracy of the TDG sensors was calculated by computing the difference between the expected reading and the TDG sensor reading (expected minus actual) for each of the four test conditions and dividing by the barometric pressure. As shown in figure 2, all of the sensor readings were within 0.5% saturation.

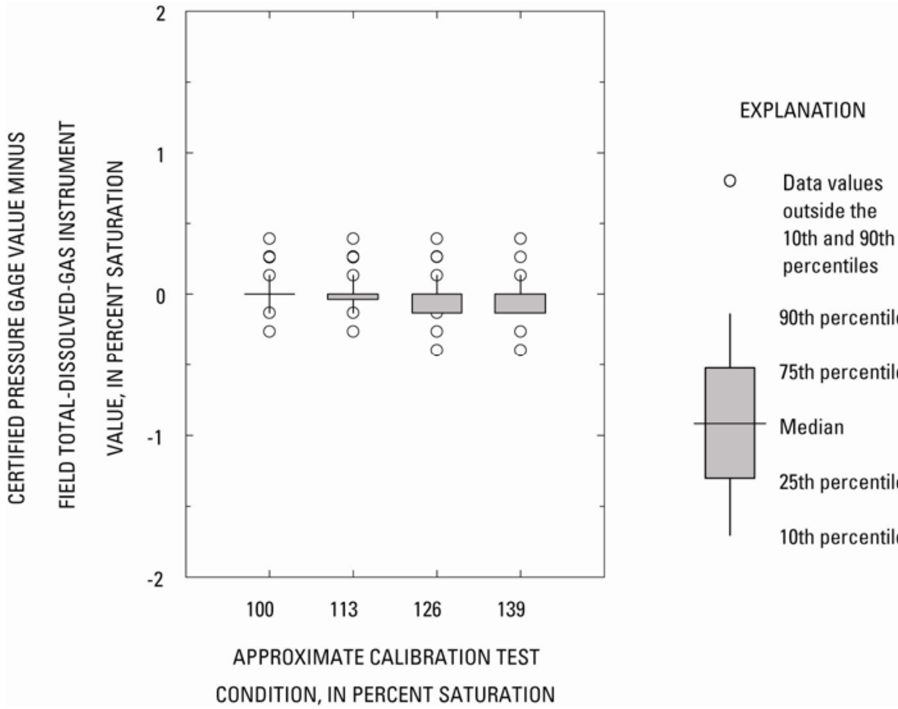

Figure 2. Accuracy of total-dissolved-gas sensors after 3 or 4 weeks of field deployment (Number of comparison values = 94).

The differences in barometric pressure, water temperature, and TDG between the secondary standard instruments and the fixed-station monitors after field deployment were measured and recorded as part of the field inspection and calibration procedure. These differences, defined as the secondary standard values minus the field instrument values, were used to compare and quantify the precision between the two independent instruments. For water temperature and TDG, the measurements were made in-situ with the secondary standard (a recently calibrated Hydrolab) positioned alongside the field Hydrolab in the river. A digital barometer, calibrated every 6 to 8 weeks, served as the secondary standard for barometric pressure. Figures 3, 4 and 5 illustrate the distribution of quality assurance data for each of the three parameters from all eight field sites.

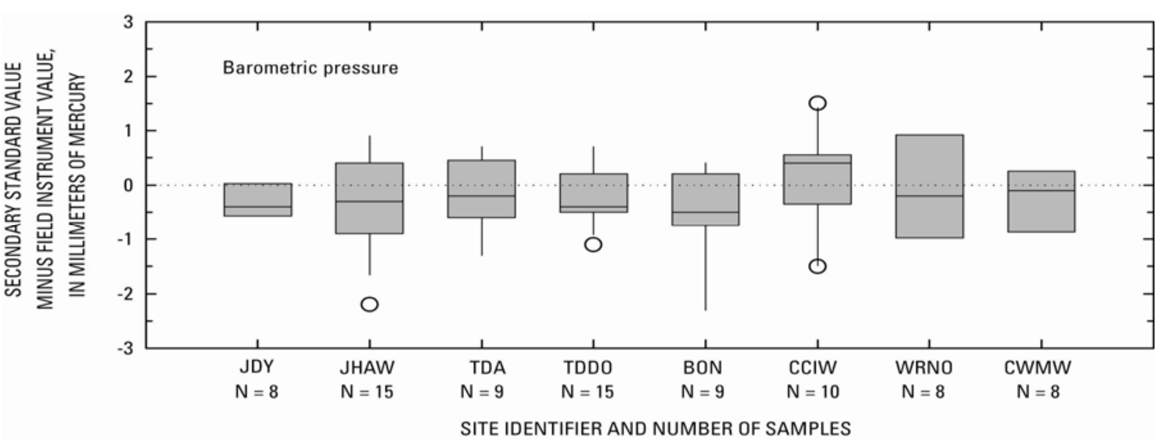

Figure 3. Difference between the secondary standard and the field barometers after 3 or 4 weeks of field deployment

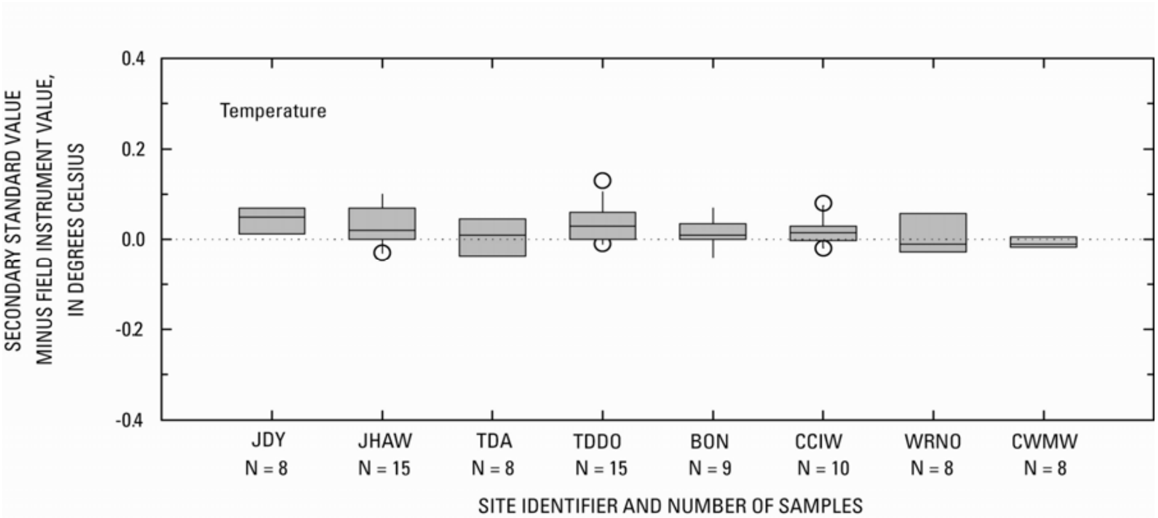

Figure 4. Difference between the secondary standard and the field temperature instruments after 3 or 4 weeks of field deployment

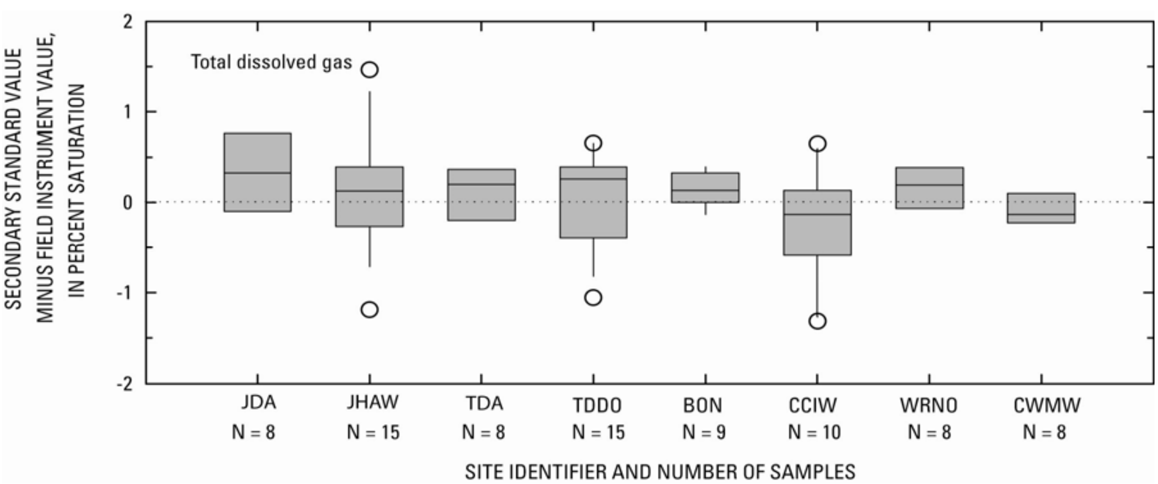

Figure 5. Difference between the secondary standard and the field total-dissolved-gas instruments after 3 or 4 weeks of field deployment

The comparisons of the digital barometer and the field barometers are shown in figure 3. All of the field values were within 2.5 mm Hg of the standard values. The secondary standard temperature sensor and the field temperature sensor results are presented in figure 4. All of the differences were within 0.2°C (degrees Celsius), with most falling within 0.1°C.

The differences between the secondary standard TDG sensor and the field TDG sensors were calculated following equilibration of the secondary standard unit to the site conditions before removing the field unit. The side-by-side equilibrium was considered complete after a minimum of 30 minutes when the TDG values for each sensor remained constant for 4 to 5 minutes.

All of the data demonstrate less than 1.5% saturation difference between the two TDG sensors, with most less than 1% saturation (fig. 5). The two greatest differences are + 1.4% saturation at John Day forebay and + 1.5% saturation at John Day tailwater. The data point at John Day forebay was recorded during the field check on May 30, 2007. The data point at John Day tailwater was recorded during the field check on July 12, 2007. Both field instruments passed post-deployment calibration tests and performed well for the rest of the field season. It is possible that more equilibration time of the secondary standard instrument would have resulted in a lesser difference between the instruments in both instances.

Effects of Spill on Total Dissolved Gas

Spill from each dam increased the level of total dissolved gas downstream. Spill data in this report are from the USACE Website (*http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html*). Night-time spill from John Day Dam occurred from April 10 to July 1; after that date, spill was continuous until it ceased on August 31 (fig. 6). Spill from The Dalles Dam (fig. 7) and from Bonneville Dam (fig. 8) was continuous from April 10 to August 31. Both Cascade Island and Warrendale are downstream of Bonneville Dam (see fig. 1), but Cascade Island was the only tailwater site with TDG levels commonly larger than 120% (fig. 9). The monitoring site at Warrendale had a planned shut-down from May 31 to September 20.

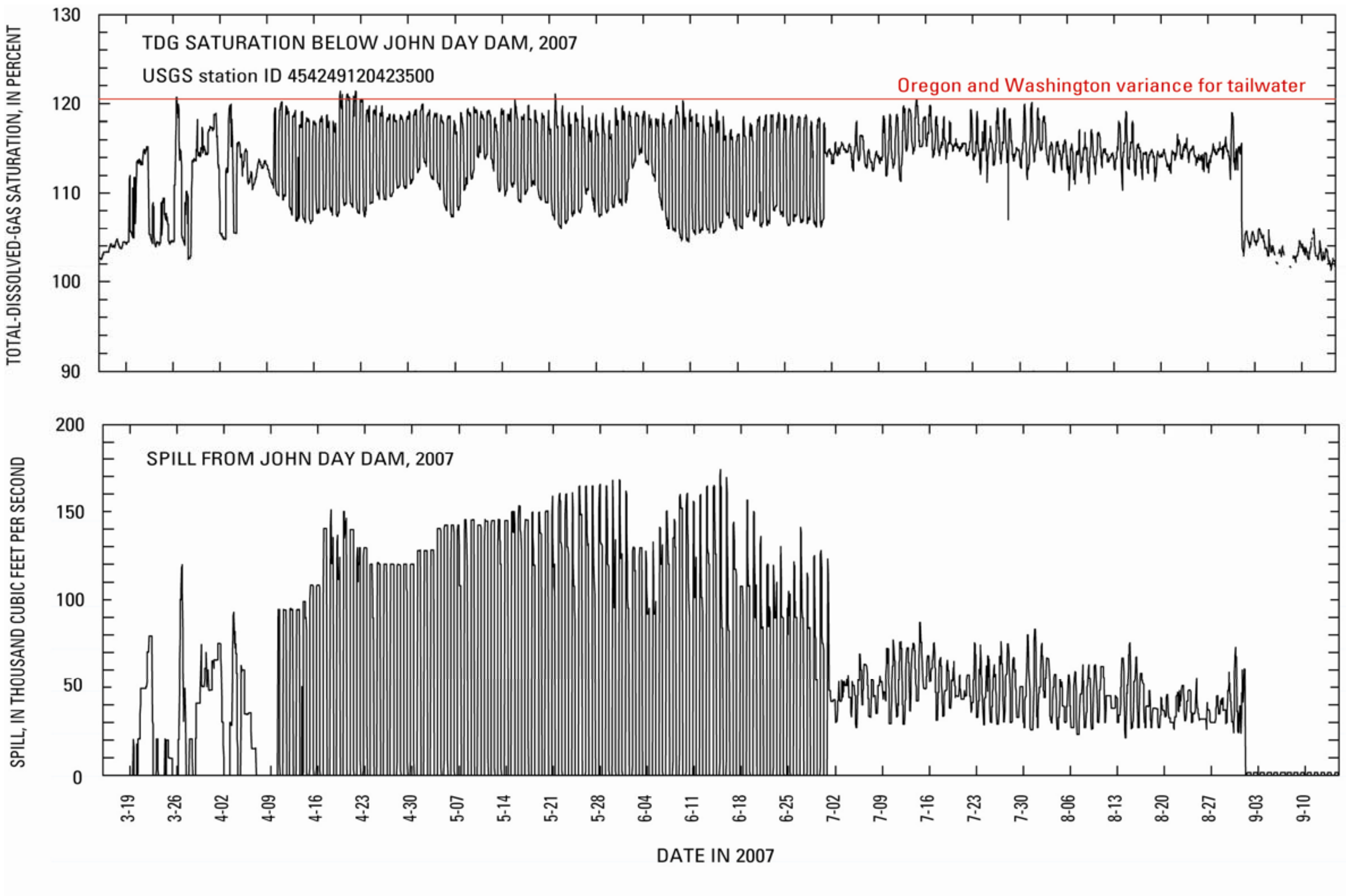

Figure 6. Total dissolved gas saturation downstream from John Day Dam and spill from John Day Dam, March 15 to September 15, 2007. (Date format = M-DD)

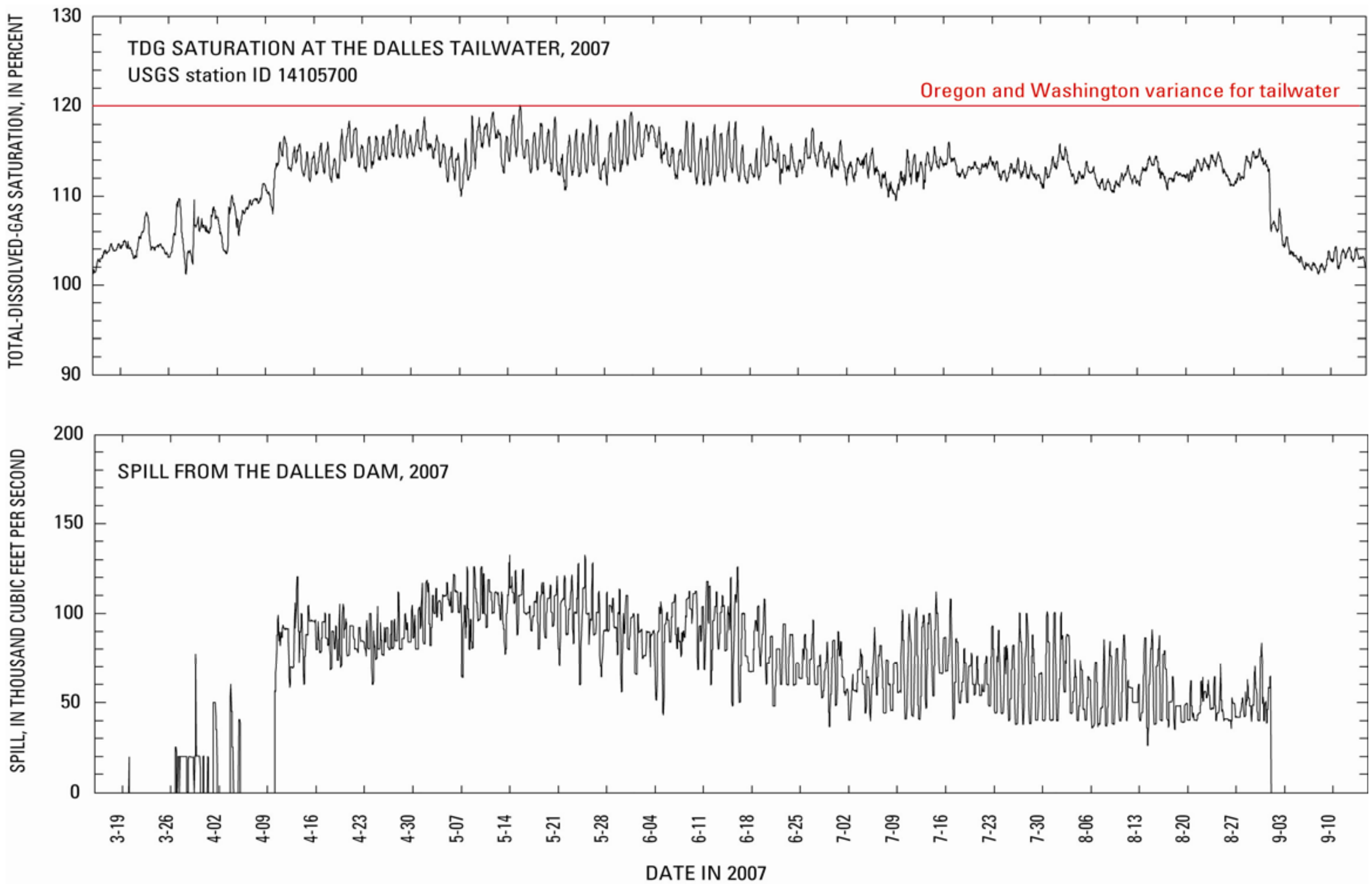

Figure 7. Total dissolved gas saturation downstream from The Dalles Dam and spill from The Dalles Dam, March 15 to September 15, 2007. (Date format = M-DD)

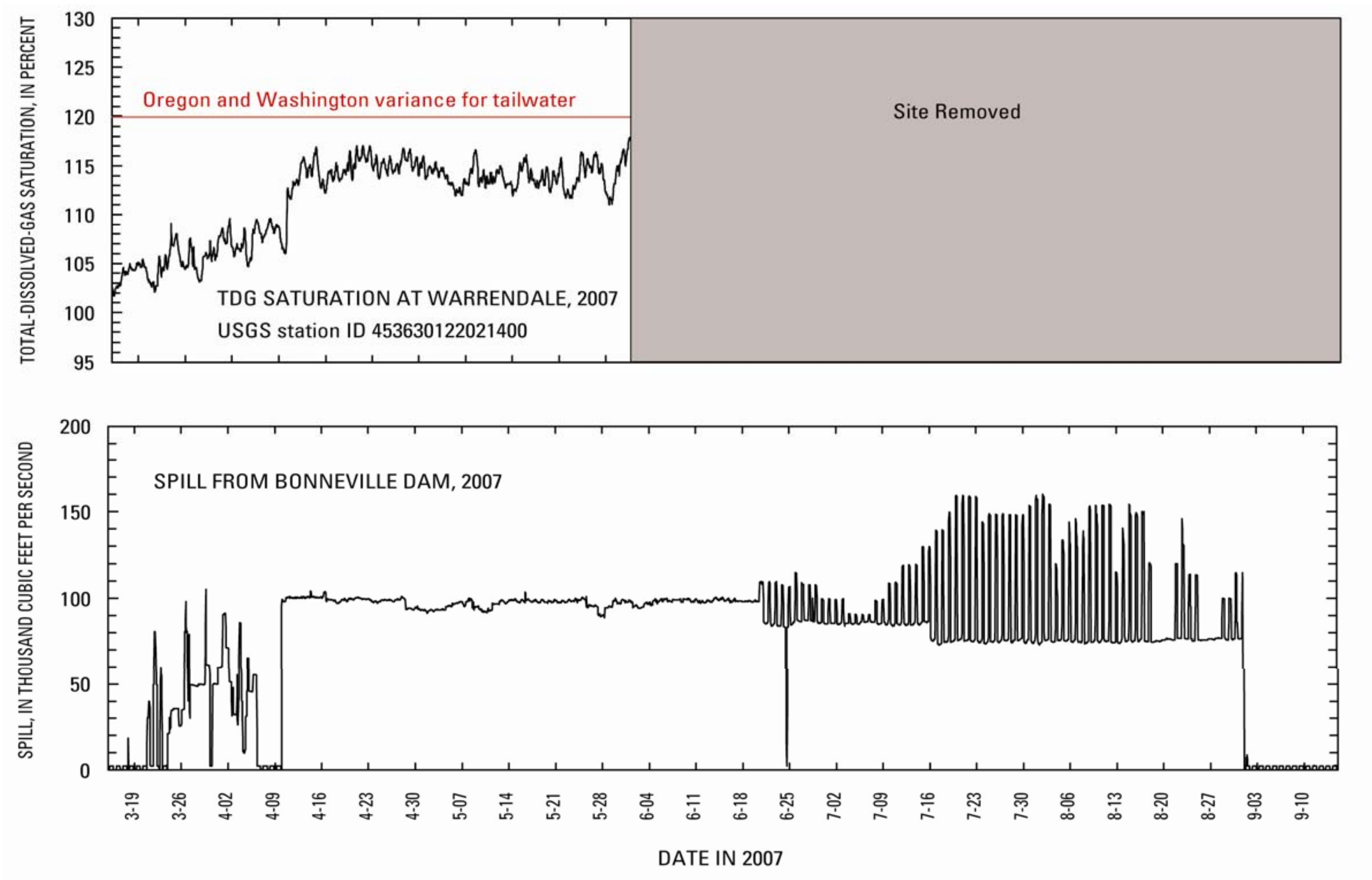

Figure 8. Total dissolved gas saturation downstream from Bonneville Dam at Warrendale and spill from Bonneville Dam, March 15 to September 15, 2007. (Date format = M-DD)

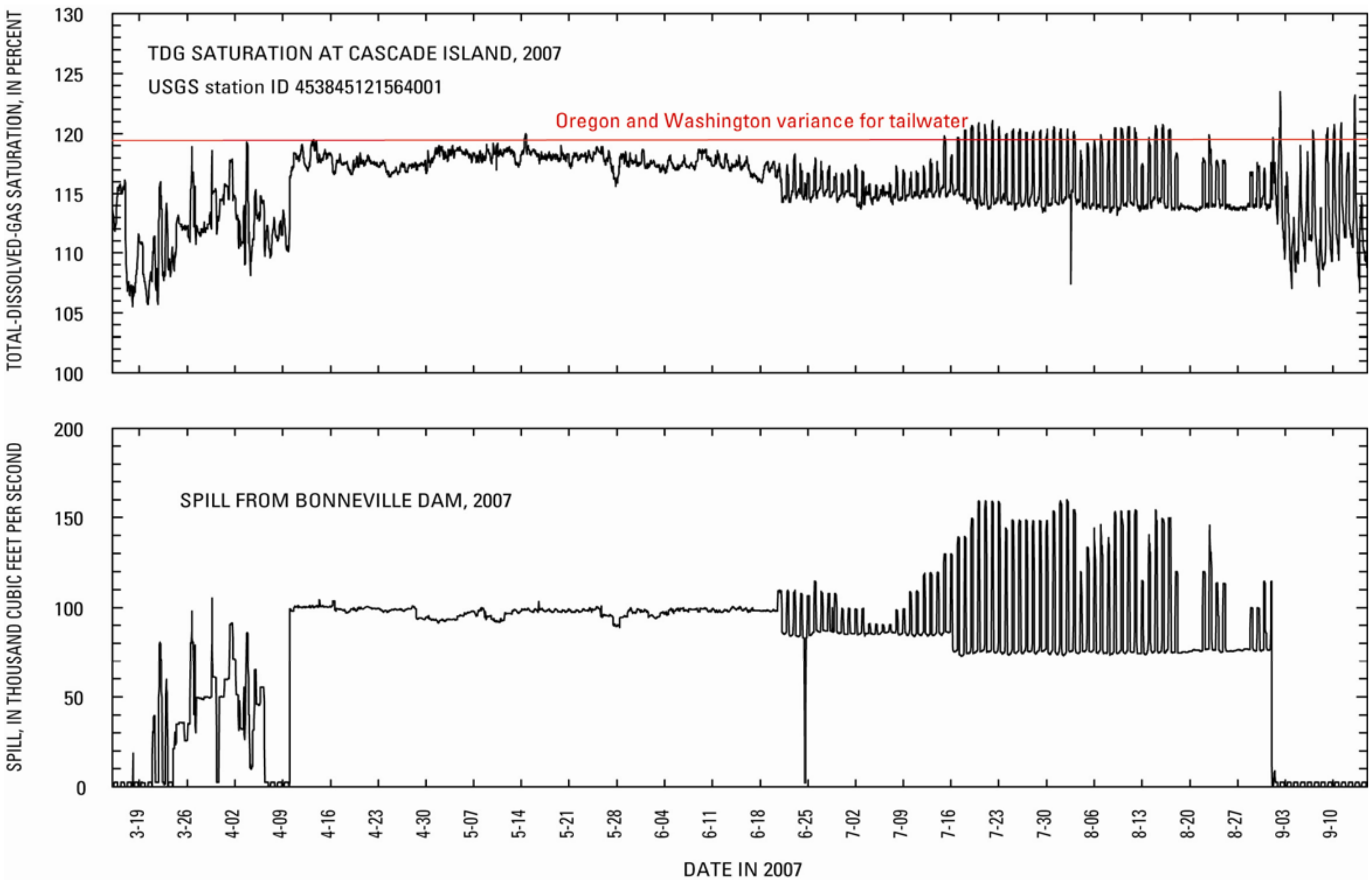

Figure 9. Total dissolved gas saturation downstream from Bonneville Dam at Cascade Island and spill from Bonneville Dam, March 15 to September 15, 2007. (Date format = M-DD)

The forebay sites, John Day navigation lock (fig. 10), The Dalles forebay (fig. 11), Bonneville forebay (fig. 12), and Camas (fig. 13), are each located immediately upstream of a dam, except for Camas, which is located 24.4 miles downstream of Bonneville Dam. As a result, the forebay sites were expected to have lower levels of total dissolved gas than the tailwater sites. Early in the 2007 spill season, TDG levels at The Dalles Dam forebay and Bonneville forebay were occasionally larger than 115% saturation due to spill from upstream dams; but after May the TDG was lower. At Camas, however, (fig 13), TDG saturation was higher than 115% on numerous occasions from April to August. As documented previously (Tanner and Bragg, 2001), some of the daily increases in TDG at Camas may have been due to the production of oxygen by aquatic plants and to temperature increases due to daytime heating.

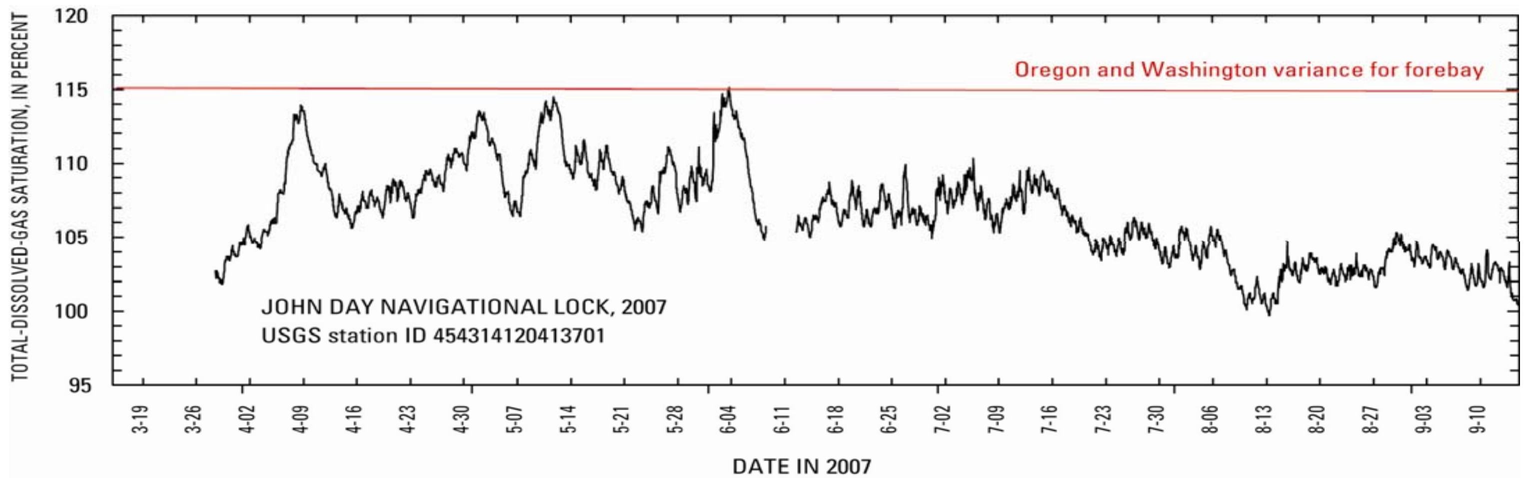

Figure 10. Total dissolved gas saturation upstream from John Day Dam, March 15 to September 15, 200**7.** (Date format = M-DD)

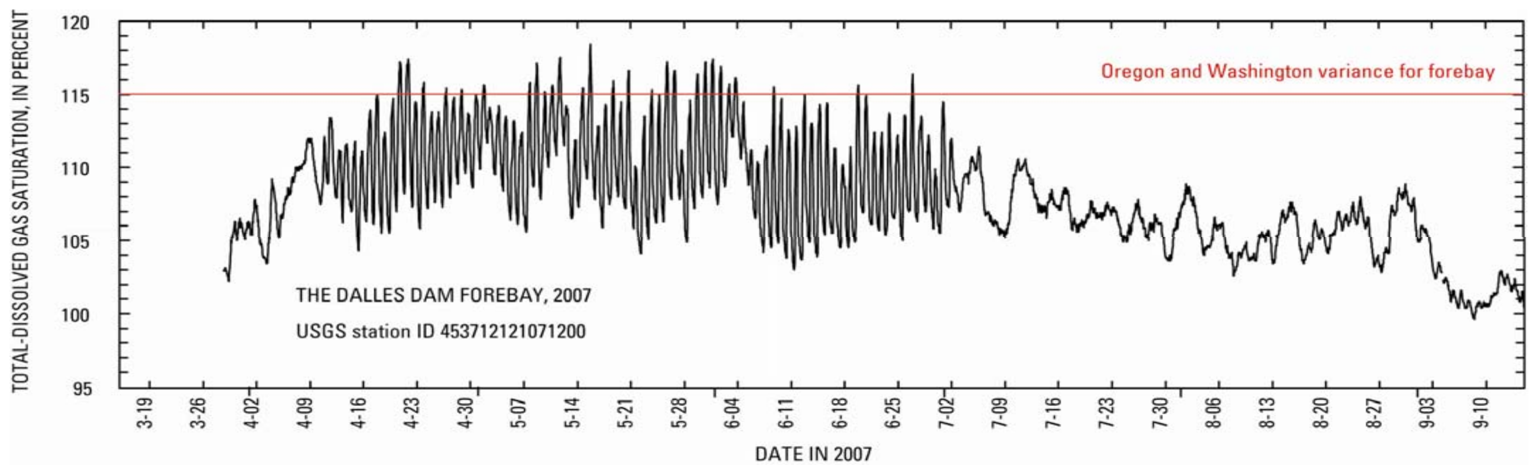

Figure 11. Total dissolved gas saturation upstream from The Dalles Dam, March 15 to September 15, 2007. (Date format = M-DD)

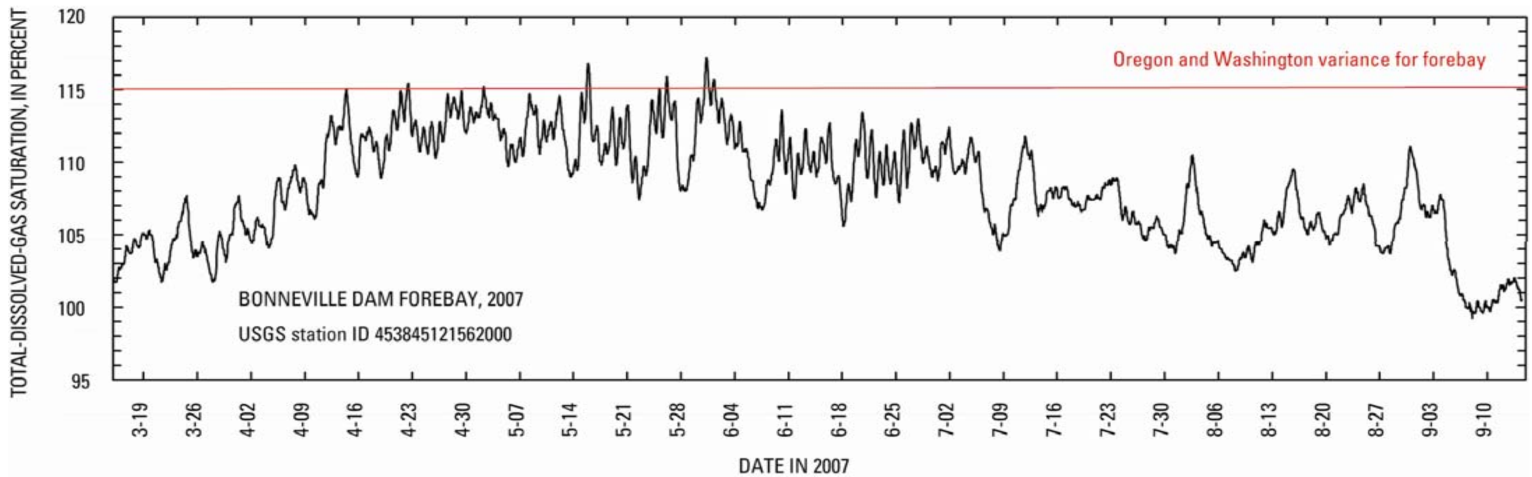

Figure 12. Total dissolved gas saturation upstream from Bonneville Dam, March 15 to September 15, 2007. (Date format = M-DD)

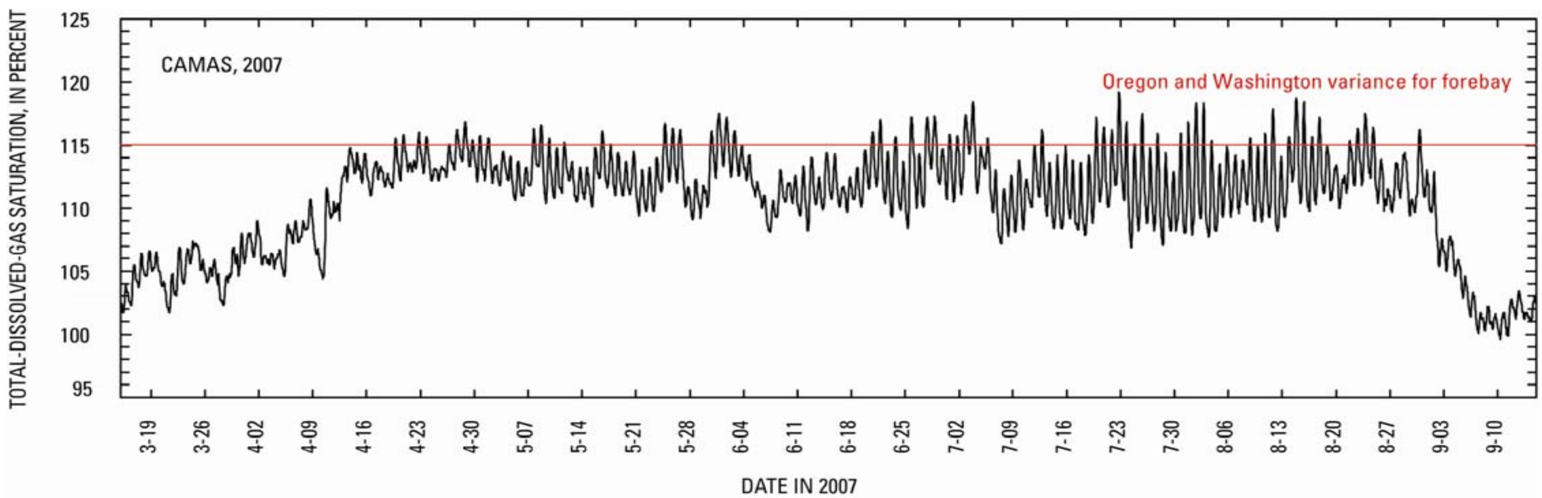

Figure 13. Total dissolved gas saturation at Camas, March 15 to September 15, 2007. (Date format = M-DD)

Comparison of Total Dissolved Gas and Temperature to Standards

In 2007, there were variances or exceptions to the water-quality standard for TDG of 110% saturation. These variances were established to allow spill for fish passage at dams on the Columbia River. The State of Oregon granted a multiyear variance, covering 2003 to 2007 (Stephanie Hallock, Oregon Environmental Quality Commission, written commun., 2003). The State of Washington provided for fish passage in its water quality standards consistent with approved gas abatement plans (Washington Administrative Code 173-201A-200(1)(f), *http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-200*, accessed November 15, 2007). From April 1 to August 31, 2007, the USACE was granted variances allowing TDG to reach 115% for forebay sites (John Day navigation lock, The Dalles forebay, Bonneville forebay, and Camas) and 120% for tailwater sites, directly downstream from dams (John Day tailwater, The Dalles tailwater, Cascade Island, and Warrendale). The 115% and 120% variances were exceeded if the average of the highest 12 hourly values in 1 day (1:00 a.m. to midnight) was larger than the numerical standard. A separate variance of 125% was in place for all sites for the highest 2-hour average (Oregon Environmental Quality Commission, written commun., 2003), or the highest 1-hour average (Washington Administrative Code 173-201A-200(1)(f), *http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-200*, accessed November 15, 2007). Although the Camas site is not located at the forebay of a dam, it is 24.4 miles downstream from Bonneville Dam and is regulated as a forebay site.

The distribution of TDG values for the spill season (April 1 to August 31, 2007) is shown in figure 14. The applicable variance is shown with the data for each site. Data from the forebay sites show an increase in the median TDG (from JDY to TDA to BON to CWMW), which probably reflects the river's inability to degas to a "baseline" level downstream of each dam before another dam is encountered to again cause an increase in TDG.

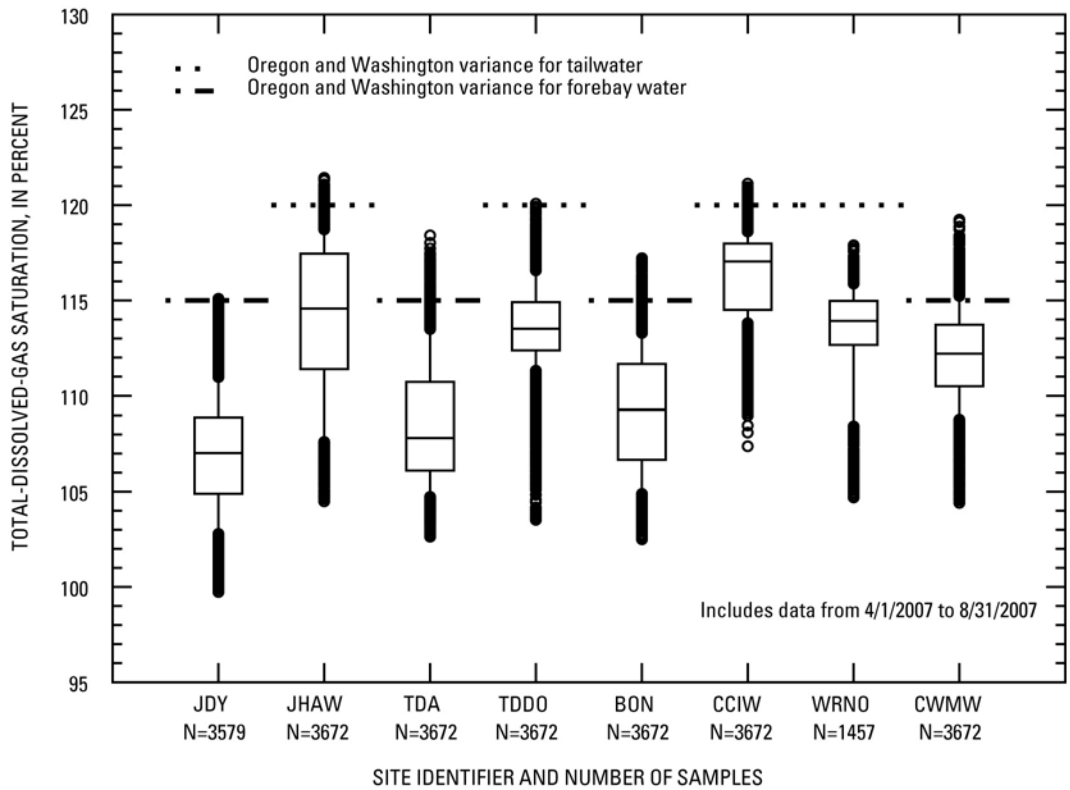

Figure 14. Distributions of hourly total-dissolved-gas data and Oregon and Washington water-quality variances, April 1, 2007, to August 31, 2007

Water temperature standards that apply to the lower Columbia River are complex and depend on the effects of human activities and the locations of salmonid rearing, spawning, and egg incubation areas. According to the State of Oregon water-quality standard, the 7-day-average maximum temperature of the lower Columbia River should not exceed 20 °C (Oregon Department of Environmental Quality, Temperature Criteria Rules OAR 340-041-0028, at *http://arcweb.sos.state.or.us/rules/OARs_300/OAR_340/340_041.html*, accessed November 9, 2007). Washington State regulations state that the water temperature in the Columbia River shall not exceed a 1-day maximum of 20.0 °C due to human activities (Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC, *http://www.ecy.wa.gov/pubs/wac173201a.pdf*, accessed November 9, 2007).

Water temperatures upstream and downstream from John Day Dam (fig. 15), The Dalles Dam (fig. 16), Bonneville Dam (fig. 17), and at Camas (fig. 18) were equal to or larger than 20.0 °C continuously from early July until mid-September. Water temperatures at the forebay sites were approximately equal to the temperatures at the tailwater sites, indicating well-mixed conditions in the forebays. At the Camas site, (fig. 18), there was a distinct daily temperature cycle, with an amplitude of about 1 °C, the minimum occurring at about 09:00 hours and the maximum at about 19:00 hours.

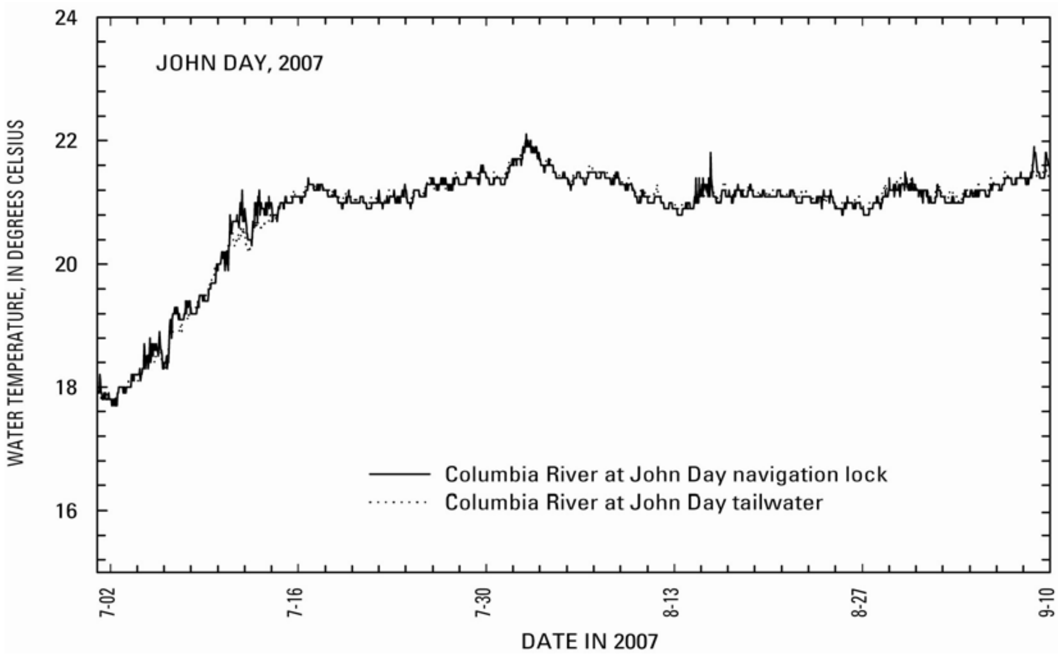

Figure 15. Water temperature upstream and downstream from John Day Dam, summer 2007

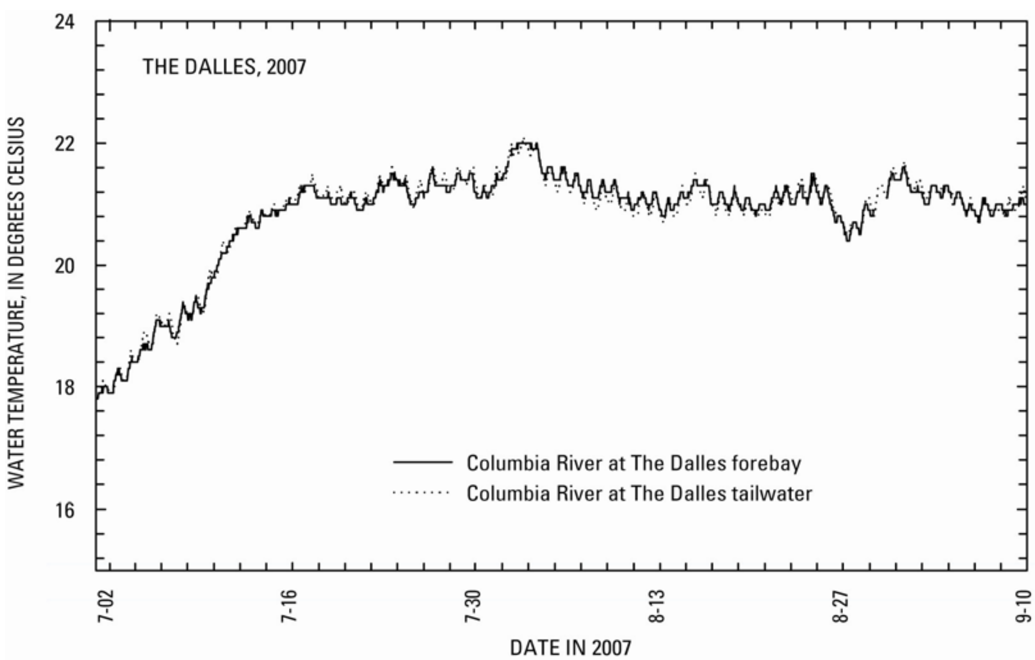

Figure 16. Water temperature upstream and downstream from The Dalles Dam, summer 2007

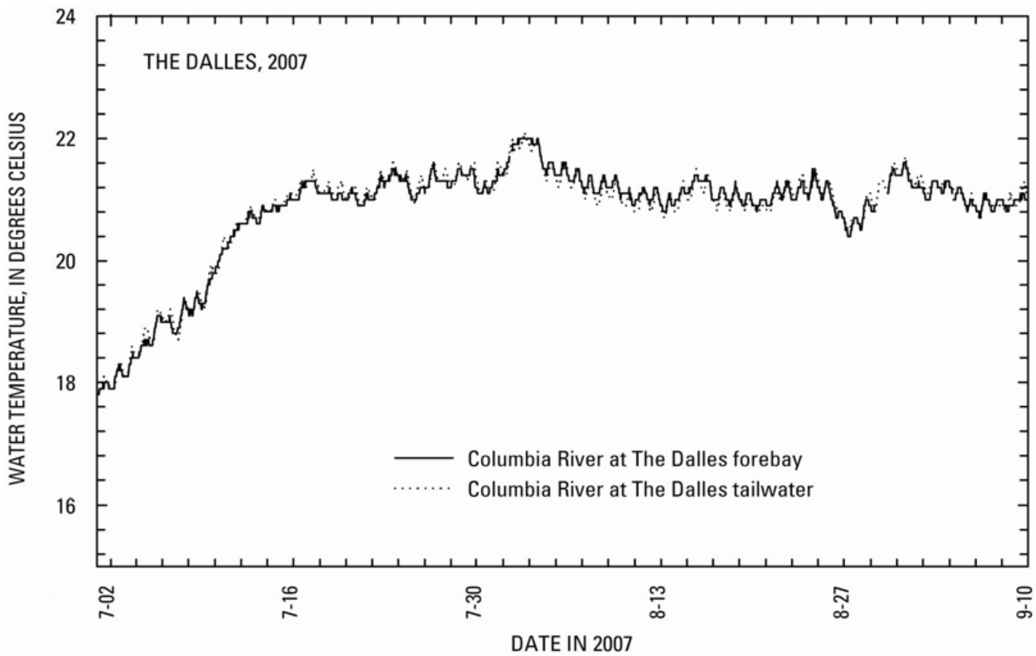

Figure 17. Water temperature upstream and downstream from Bonneville Dam, summer 2007

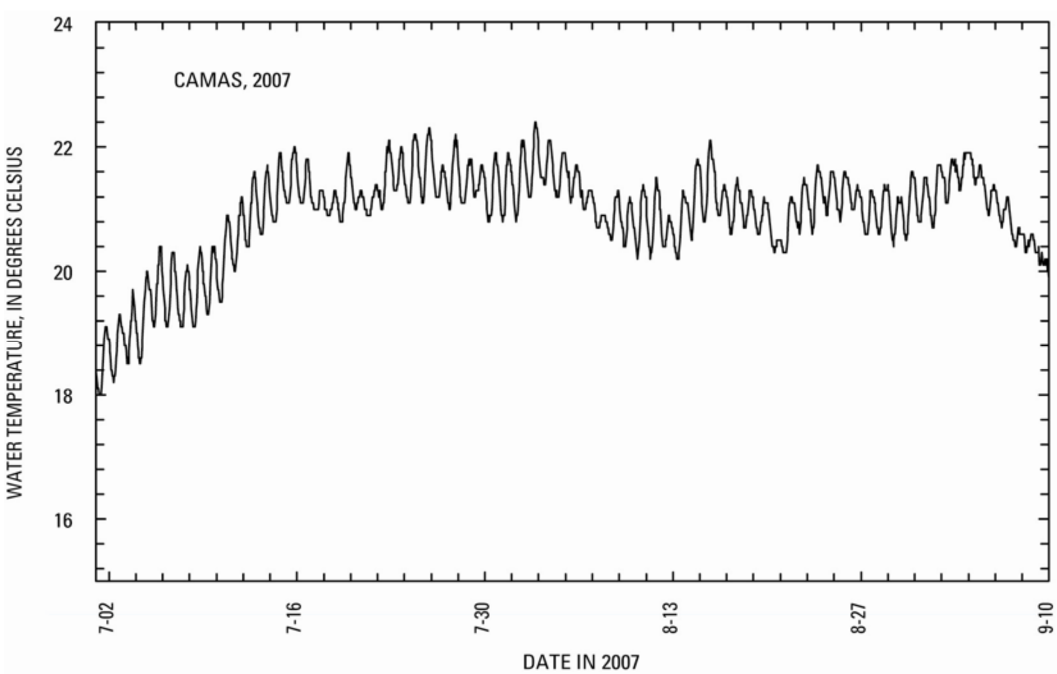

Figure 18. Water temperature at Camas, summer 2007

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